FILAMENT HOUSING FOR FIBER SPLICING AND LENS FABRICATION PROCESSES

Background of Invention

Field of the Invention

[0001] The invention relates to a method and an apparatus for optically coupling a fiber to an optical element such as a lens or another fiber.

Background Art

[0002] Fiber collimators are used in almost all micro-optic devices to couple light between optical fibers and micro-optic elements. Figure 1 shows a micro-optic device **1** comprising micro-optic elements **2**, such as filters, polarizers, etc., aligned with an input fiber **3** and an output fiber **4**. Because optical fibers are divergent in nature, when the light **7** transmitted through the input fiber **3** exits the fiber, it diverges rapidly. A collimating lens **5**, such as ball lens, graded-index (GRIN) lens, asphere, etc., is inserted at the end of the input fiber **3** to collimate the light. Another collimating lens **6** is inserted at the output fiber **4** to gather the light after it has passed through the micro-optic elements **2**. To ensure proper optical coupling, the collimating lenses **5**, **6** must be properly aligned with the optical fibers **3**, **4** in three dimensions.

[0003] Various mechanical methods for coupling lenses to optical fibers are known in the art. Figure 2 shows an example where an optical fiber **10** is mechanically coupled to a lens **12** by an alignment device **14**. A refractive-index matching agent **16** is disposed between the optical fiber **10** and lens **12** to minimize reflection of the light signal. Coupling the lens **12** to the optical fiber **10** in the manner shown in Figure 2 requires aligning the optical fiber **10** and the optical axis position of the lens **12** at submicron level. This process can be very time consuming. Because the lens **12** is independent of the optical fiber **10** and must be precisely aligned with the optical fiber **10**, fabricating this type of fiber-optic system is expensive and may result in decreased efficiency in optical coupling. This is also true for independent lens systems that are

attached to optical fibers by other means such as gluing. In the case of gluing, the materials used to bond the lens to the fiber can present reliability problems in terms of micro-movement of the lens and fiber in hostile operating conditions.

[0004] U.S. Patent No. 5,293,438 issued to Konno *et al.* proposes a solution which includes integrally forming the lens with the fiber using a fusion process. An optical fiber with an integrally formed lens is referred to as a microlensed fiber. Referring to Figure 3, a method for forming a microlensed fiber **20** involves fusion-splicing an optical fiber **22** to a rod **24**. The rod **24** is made of a lens material such as silica or borosilicate. A lens **26** is formed from the rod **24** by a fusion process. One of the primary advantages of a microlensed fiber is simplified packaging because the lens is already aligned with and integrally formed with the fiber. Thus, there is no need for mechanically attaching or gluing the lens to the fiber. Also, a microlensed fiber can be made in a wide range of sizes so that its spot size and working range can be tailored for a particular application. Microlensed fiber consisting of silica plano-convex lens fusion-spliced to an optical fiber has been proposed as a replacement for GRIN lens in micro-optic packages.

[0005] In general, fabrication of a microlensed fiber involves four basic steps: (1) prepositioning, (2) splicing, (3) taper cutting, and (4) melting back. Referring to Figure 2, prepositioning involves aligning the optical fiber **22** with the rod **24**. The optical fiber **22** and the rod **24** are axially aligned with ends proximal each other in a way similar to aligning two fibers for standard fusion splicing. Splicing involves pushing the opposing ends of the optical fiber **22** and the rod **24** together while heating them to fuse or melt the ends together. Taper cutting involves moving the heat source to a desired location along the rod **24** to taper the rod **24** to a desired length. Melting back involves moving the heat source back towards the splice **25**, *i.e.*, the joint between the optical fiber **22** and the rod **24**, by a selected distance to form the lens **26**. The distance the heat source is moved back towards the splice **25** depends on the desired radius of curvature for the lens **26**. The closer the heat source is to the splice **25**, the larger the radius of curvature of the lens **26**.

[0006] Fabrication of a microlensed fiber, such as the microlensed fiber **20** shown in Figure 3, requires a uniform heat source to allow for a formation of a substantially perfectly spherical lens **26** at the end of the fiber **22**. One possible heat source is a

standard fusion splicer with a tungsten filament. Figure 4 shows a cassette **30** used in a standard fusion splicer. The cassette **30** includes a tungsten filament loop **32**, which has been shown to provide exceptionally uniform heat that allows for the formation of a spherical lens with a symmetrical circular mode field. An example of this type of standard fusion splicer is one sold under the trade name FFS-2000 by Vytran Corporation of Morganville, New Jersey. However, manufacturing microlensed fibers using a standard fusion splicer, such as sold under the trade name FFS-2000 by Vytran Corporation, has not been practical because the lifetime of the filament of the fusion splicer is very short, at least in comparison to when the fusion splicer is used for fusion-splicing of fibers. The reasons for this short filament lifetime are discussed below.

[0007] Filament powers required during fabrication of a microlensed fiber are generally higher than the filament power required for standard fusion-splicing of fibers. For example, using a standard filament loop on a Vytran FFS-2000 splicer with a 15 Amp DC power supply, the filament powers required to fabricate a microlensed fiber from an optical fiber, such as a Corning® SMF-28™ optical fiber, and a 200 micron diameter silica rod are 21 W for splicing, 26 W for taper cutting, and 31 W for melting back. On the other hand, the filament power required for standard fusion-splicing of optical fibers, such as a Corning® SMF-28™ optical fiber to another Corning® SMF-28™ optical fiber, is 21 W. Table 1 below shows typical filament powers required for fabrication of microlensed fiber depending on rod material.

Table 1: Filament powers required for fabrication of microlensed fiber

Process	**Filament Power (Watts, W)**		
	Silica	B_2O_3-SiO_2	GeO_2-SiO_2
Splicing	21	18	19
Taper cut	26	21	24
Melt back	31	24	26

[0008] In addition, during fabrication of a microlensed fiber, the filament is on much longer than when used to make a standard fiber-to-fiber splice. For example, the filament of the fusion splicer sold under the trade name FFS-2000 by Vytran

Corporation is on an average of about 25 seconds when forming a lens using the method described above and only an average of 5 seconds when forming a standard fiber-to-fiber splice. Because the filament powers for lens formation are much higher and the filament stays on much longer, the lifetime of the filament is greatly reduced when used for lens fabrication. For example, while a filament, such as the filament of the fusion splicer sold under the trade name FFS-2000 by Vytran Corporation, can typically make around 500 fiber-to-fiber splices, it is typically only capable of making a maximum of about 80 lenses when silica is used as the lens material and about 150 lenses when borosilicate glass is used as the lens material.

[0009] Another reason for a short filament lifetime using existing technology, such as the FFS-2000 fusion splicer sold by Vytran Corporation, is that the tungsten filament of the fusion splicer is exposed to air. In the current fusion processes, the filament loop, which is run with a DC current, sits inside a splice head that is completely open to air. Exposure of the tungsten filament to air results in tungsten oxidation. When the filament is used for splicing or making a lens, the filament is purged with argon at about 0.5 to 1 L/min. However, when the filament is not in use, it is exposed to air. Tungsten oxide has a much lower melting point than tungsten metal, which leads to constant evaporation of oxidized tungsten from the surface of the filament until the filament is so thin that it breaks.

[0010] Although other sources of heat, such as a CO_2 laser, may potentially be used for fabricating a microlensed fiber, these sources have not been shown to provide heat that is sufficiently uniform and controlled to allow for the level of lens reproducibility necessary for production. On the other hand, filament loops, such as in fusion splicers, have been shown to achieve a select rate of 90% or better in the production of microlensed fiber with a working distance of 4 mm when borosilicate glass is used as the lens material. The term "select rate" is the number of lenses that meet the specification. With a working distance of 4mm, the size of lenses that can be made is limited. However, larger lenses can be made if the filament loop is made larger. Because filament lifetime is a major limitation on fabrication processes for microlensed fiber, a new apparatus and method for increasing the lifetime of a filament is needed and desired.

Summary of Invention

[0011] In one aspect, the invention relates to an apparatus for conducting a fusion process which comprises a first chamber and a second chamber maintaining an atmosphere that is substantially free of oxygen. A closeable passage connects the first chamber and the second chamber and selectively provides substantial isolation of the second chamber from the first chamber. A filament normally disposed in the second chamber is movable between the second chamber and the first chamber when the closeable passage is in an open position.

[0012] In another aspect, the invention relates to an apparatus for conducting a fusion process which comprises a first chamber and a plurality of second chambers. A closeable passage connects a selected one of the second chambers to the first chamber and selectively provides substantial isolation of the selected one of the second chambers from the first chamber. A filament disposed in the selected one of the second chambers is movable between the selected one of the second chambers and the first chamber when the closeable passage is in an open position. The selected one of the second chambers maintains an atmosphere that is substantially free of oxygen.

[0013] In another aspect, the invention relates to an apparatus for fabricating a microlensed fiber which comprises a first chamber having a plurality of fiber holders through which fibers are inserted into the first chamber. The apparatus further includes a second chamber which maintains a substantially inert atmosphere. A closeable passage disposed between the first chamber and the second chamber selectively provides substantial isolation of the second chamber from the first chamber. A filament normally disposed in the second chamber is movable between the second chamber and the first chamber when the closeable passage is in an open position.

[0014] In another aspect, the invention relates to a method for extending a lifetime of a filament used in a fusion process. The method comprises disposing the filament in a second chamber which maintains an atmosphere that is substantially free of oxygen, extending the filament into a first chamber for the fusion process, and retracting the filament back into the second chamber after the fusion process.

[0015] In another aspect, the invention relates to a method for making microlensed fibers which comprises aligning a fiber and a rod made of lens material in a first chamber. The method further comprises extending a filament from a second chamber which maintains an atmosphere that is substantially free of oxygen to the first chamber. The method further comprises fusion splicing the fiber to the rod and forming a lens from the rod using the filament.

[0016] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

Brief Description of Drawings

[0017] Figure 1 is a schematic representation of a micro-optic device.

[0018] Figure 2 is a schematic of a prior art method for coupling a lens to an optical fiber.

[0019] Figure 3 is a schematic of a prior art microlensed fiber.

[0020] Figure 4 shows a prior art fusion splicer with a filament loop.

[0021] Figure 5 is a front view of an apparatus for fabricating a microlensed fiber in accordance with one embodiment of the invention.

[0022] Figure 6A is a vertical cross-section of the apparatus shown in Figure 5.

[0023] Figure 6B is a horizontal cross-section of the apparatus shown in Figure 5.

[0024] Figure 7 is a front view of an apparatus for fabricating a microlensed fiber in accordance with another embodiment of the invention.

[0025] Figure 8 shows filament chambers mounted on a carousel.

Detailed Description

[0026] Various embodiments of the invention will now be described with reference to the accompanying drawings. Figure 5 shows an apparatus **100** for fabricating a microlensed fiber in accordance with one embodiment of the invention. The apparatus **100** may also be used for fusion-splicing of fibers or for other processes involving use of a filament in general. The apparatus **100** comprises a first chamber

110 and a second chamber **120**. The first chamber **110**, hereafter referred to as the fiber chamber **110**, is adapted to permit loading and aligning of fibers **114a**, **114b** for a fiber splicing or lens fabrication process. In the case of making microlensed fiber, either element **114a** or **114b** is a glass rod with no core. Preferably, element **114b** is a glass rod. The second chamber **120**, hereafter referred to as the filament chamber **120**, is adapted to house a filament (not shown) in an inert atmosphere when the filament is not in active use, such as when fibers **114a**, **144b** are being loaded into or unloaded from the fiber chamber **110**. The chambers **110**, **112** may be made of a corrosion-resistant material such as stainless steel.

[0027] As shown in Figure 6A, the fiber chamber **100** and the filament chamber **120** are connected by a closeable passage **140**. The closeable passage **140** provides selective, substantial isolation of the filament chamber **120** from the fiber chamber **110**. Preferably, the passage **140** is substantially airtight when closed to minimize airflow from the fiber chamber **110** into the filament chamber **120**. In the illustrated embodiment, a door **141** is provided to block off or open the closeable passage **140**. For convenience, the door **141** may be a sliding door that is slidable relative to the closeable passage **140**. Alternatively, the door **141** may be a conventional hinged door, similar to those found in multiple-chamber glove boxes. In another embodiment, a gate valve (not shown) may be used in lieu of the door **141** to control access between the fiber chamber **110** and filament chamber **120**. A gate valve is a seal when closed. Various types of gate valves suitable for this purpose are available from, for example, MDC Vacuum Products Corporation, Hayward, California.

[0028] When the apparatus **100** is used for fabricating a microlensed fiber, such as microlensed fiber **20** shown in Figure 3, one of the fibers **114a**, **114b** is made of a lens material such as silica or borosilicate. In the following description, the fiber **114b** is assumed to be the fiber that is made of a lens material. Hereafter, the fiber **114b** may be referred to as lens material rod **114b**. As can be seen in the drawing, the fiber **114b** has a larger diameter than the fiber **114a**. The fibers **114a**, **114b** are inserted into the fiber chamber **110** through fiber holders **112** coupled to opposite sides of the fiber chamber **110**. The fiber holders **112** have grooves **113**, such as V-grooves, for receiving the fibers **114a**, **144b**. In one embodiment, the apparatus **100** includes a conventional positioning device (not shown for clarity), such as an x-y-z stage or

other actuator, coupled to each of the fiber holders **112** to enable controllable alignment of the fibers **114a, 114b** within the fiber chamber **110**. In one embodiment, the fiber chamber **110** includes one or more viewing ports **118**, such as fused silica windows, which allow for the use of cameras (**144** in Figure 5) or other viewing devices to assist in alignment and prepositioning of the fibers **114a, 114b** before the microlensed fiber is made.

[0029] A filament support structure **132** is disposed in the filament chamber **120**. The filament support structure **132** comprises a head **133** which holds a filament cassette **135**. As shown in Figure 6B, the filament cassette **135** comprises an insulating plate **138** and electrodes **137** which extend through the insulating plate **138**. One end of the electrodes **137** is coupled to a power supply (not shown) through, for example, leads **142**. The other end of the electrodes **137** is coupled to a filament **130**. The electrodes **137** support and provide power to the filament **130**. In one embodiment, the filament **130** is made of tungsten. The filament support structure **132** is movable between the filament chamber **120** and the fiber chamber **110** through the closeable passage **140**. In one embodiment, a positioning device **134**, such as a y-z stage, is coupled to the filament support structure **132** to provide controllable alignment of the filament **130** with the fibers (**114a, 114b** in Figure 6A) in the fiber chamber **110**. An optical sensor **136** may also be coupled to the filament support structure **132** to detect a gap (**139** in Figure 6A) between the fibers (**114a, 114b** in Figure 6A) to ensure, for example, that the filament **130** is centered at the gap (**139** in Figure 6A) prior to fusion splicing of the fibers (**114a, 114b** in Figure 6A).

[0030] The filament chamber **120** maintains an inert atmosphere so that oxidation of the filament **130** is reduced. For example, a vacuum pump (not shown) may be coupled to a port **122** in the filament chamber **120** to evacuate the filament chamber **120**. An inert gas source (not shown) may be coupled to a port **124** in the filament chamber **120** to supply the filament chamber **120** with an inert gas, such as argon or an argon-hydrogen mixture, so that a substantially air-free atmosphere can be maintained in the filament chamber **120**. Baffles **126** may be provided at the ports **122, 124** to impede flow of gas into and out of the filament chamber **120**. Mass flow controls (not shown) may be provided as necessary to control gas flow into and out of the filament chamber **120**

[0031] Preferably, the fiber chamber **110** also maintains an inert atmosphere, at least around the filament **130**, when the filament **130** is in use. For example, a port **116** in the fiber chamber **110** may be coupled to an inert gas source, such as argon. A vacuum pump (not shown) may be used to evacuate the fiber chamber **110** prior to pumping the inert gas into the fiber chamber **110**. To minimize air leakage into the fiber chamber **110** during loading and unloading of fibers **114a**, **114b**, the inert gas is supplied into the fiber chamber **110** at a higher pressure than the ambient pressure. Mass flow controls (not shown) may be provided as necessary to control gas flow into and out of the fiber chamber **110**.

[0032] Referring to Figure 6A, to fabricate a microlensed fiber, the filament support structure **132**, which holds the filament (**130** in Figure 6B), is first disposed in the filament chamber **120** in an inert atmosphere. At this time, the closeable passage **140** between the filament chamber **120** and the fiber chamber **110** is closed so that the fiber **114a** and lens material rod **114b** can be inserted into the fiber chamber **110** without exposing the filament (**130** in Figure 6B) to air. As the fiber **114a** and lens material rod **114b** are inserted into and aligned within the fiber chamber **110**, the fiber chamber **110** is purged with the inert gas supplied through the port **116**. The passage **140** is then opened to permit the filament support structure **132** to move into the fiber chamber **110**.

[0033] When the filament (**130** in Figure 6B) is in the fiber chamber **110**, power is supplied to the filament (**130** in Figure 6B) to form the microlensed fiber. To form the microlensed fiber, the fiber **114a** and lens material rod **114b** are spliced by pushing their opposing ends together while being heated by the filament (**130** in Figure 6B). After splicing, the filament (**130** in Figure 6B) is moved by a desired distance along the lens material rod **114b** to taper (or cut) the lens material rod **114b** to a desired length. After tapering the lens material rod **114b**, the filament (**130** in Figure 6B) is moved towards the splice, *i.e.*, the joint formed between the fiber **114a** and the lens material rod **114b**, by a distance that depends on the desired radius of curvature of the lens to be formed on the lens material rod **114b**. In general, the closer the filament (**130** in Figure 6B) is to the splice, the larger the radius of curvature of the lens formed. After the microlensed fiber is formed, the filament support structure **132** is retracted back into the filament chamber **120**, and the passage

140 is closed to preserve the inert atmosphere in the filament chamber **120**. The microlensed fiber is then removed from the fiber chamber **110**, and the process is repeated again for fabrication of other microlensed fibers.

[0034] Viewing devices, *e.g.*, camera **144** in Figure 5, may be used to capture the lens image and measure lens dimensions after the lens has been made. In general, it has been determined that the filament (**130** in Figure 6B) makes lenses with very reproducible radius of curvature when borosilicate glass is used. However, to make the correct length of lens, the position the filament (**130** in Figure 6B) should move to during the taper cut may need to be adjusted periodically using an algorithm that calculates the desired length of the lens. In one embodiment, the taper cut steps (or position the filament should move to) are adjusted based on measurement of thickness of the previous lens. In this embodiment, the adjustment is done so that the ratio of the thickness of the lens to the radius of curvature of the lens is substantially constant, as shown by the following equation:

$$T_{new} = T_{old} + \frac{\left(\frac{T_{measured}}{R_{measured}} - \frac{T_{target}}{R_{target}}\right) \cdot R_{measured}}{F} \qquad (1)$$

where T_{new} is the adjusted number of taper cut steps for the next lens to be made, T_{old} is the number of taper cut steps used in making the previous lens, $T_{measured}$ is the measured thickness of the lens, $R_{measured}$ is the measured radius of curvature of the lens, T_{target} is the target thickness of the lens, R_{target} is the target radius of curvature of the lens, and F is the dampened step size of the splice head (**133** in Figure 6B) moving along the fiber-optic axis. Dampening is determined experimentally to achieve a stable process. Typically, the ratio T_{target}/R_{target} is about 3.5. Equation (1) above may be used to control the positioning device (**134** in Figure 6A) coupled to the filament support structure (**132** in Figure 6A).

[0035] Those skilled in the art will appreciate that various modifications can be made to the apparatus **100** shown in Figures 5-6B which are within the scope of the invention. For example, as shown in Figure 7, the fiber chamber **110** and filament chamber **120** may be structurally independent chambers, *i.e.*, not placed immediately adjacent to each other. The filament chamber **120** and fiber chamber **110** may be connected to a passage **146**. One end of the passage **146** would communicate with the

fiber chamber **110** through an aperture (not shown) in the fiber chamber **110**, and the other end of the passage **146** would communicate with the filament chamber **112** through an aperture (not shown) in the filament chamber **112**. The filament support structure (**132** in Figure 6B) could then pass through the passage **146** into the fiber chamber **110**. One or both of the chambers **110**, **120** may include a door (not shown) or gate valve adapted to selectively block the corresponding aperture (not shown) so that the filament chamber **120** can be selectively isolated from the fiber chamber **110**, such as during loading and unloading of fibers **114a**, **114b** in the fiber chamber **110**. Alternatively, a door, valve, or other closable device may be disposed in the passage **146**.

[0036] In another embodiment, to facilitate removal of the filament (**130** in Figure 6B) when burnt out, the filament support structure (**132** in Figure 6B) and translation stage (**134** in Figure 6B) can be attached to a flange (not shown). The flange (not shown) may then be mounted on the filament chamber (**120** in Figure 6B). When it is desired to change the filament (**130** in Figure 6B), the flange can be quickly removed from the filament chamber (**120** in Figure 6B) and replaced with another flange that a filament support structure with a new filament and a translation stage attached to it. Alternatively, as shown in Figure 8, multiple filament chambers **120** may be loaded on a turntable **148**, or the like. Any one of the filament chambers **120** may be connected to the fiber chamber **110** at any given time while any burnt out filaments are replaced in the other filament chambers **120**.

[0037] The invention may provide general advantages. By minimizing exposure of the filament to an oxidizing atmosphere during operation, the lifetime of the filament is increased. The configuration of the apparatus can be adjusted as necessary to allow for fabrication of larger lenses.

[0038] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.